Chapter 2
The Importance of Imperviousness

Introduction

The emerging field of urban watershed protection often lacks a unifying theme to guide the efforts of its many participants— planners, engineers, landscape architects, scientists, and local officials. The lack of a common theme has often made it difficult to achieve a consistent result at either the individual development site, or cumulatively, at the watershed scale.

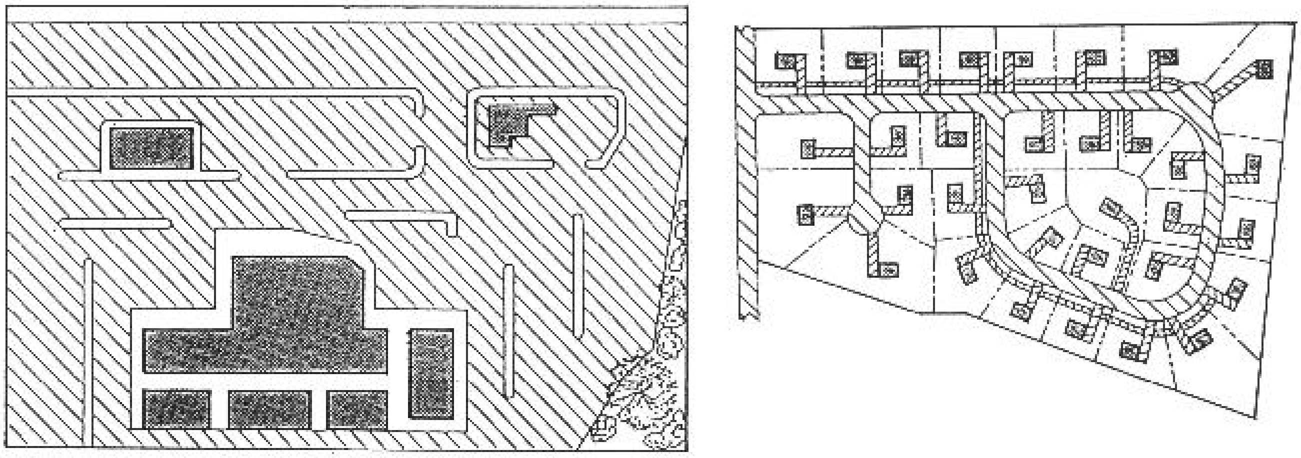
In this chapter, a unifying theme is proposed based on a physically defined unit— impervious cover. Imperviousness here is defined as the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces of the urban landscape. This variable can be easily measured at all scales of development, as the percentage of area that is not "green."

Imperviousness is a very useful indicator with which to measure the impacts of land development on aquatic systems. Reviewed here is the scientific evidence that relates impervious cover to specific changes in the hydrology, habitat structure, water quality and biodiversity of aquatic systems. This research, conducted in many geographic areas, concentrating on many different variables, and employing widely different methods, has yielded a surprisingly similar conclusion— stream degradation occurs at relatively low levels of imperviousness (10–20%). Most importantly, imperviousness is one of the few variables that can be explicitly quantified, managed and controlled at each stage of land development. The remainder of the chapter explores the relationship between impervious cover and stream quality to set the stage for later chapters that examine how impervious cover can be managed or reduced during land development.

The Components of Imperviousness

Imperviousness represents the imprint of land development on the landscape. It is composed of two primary components—the *rooftops* under which we live, work and shop, and the *transport* system (roads, driveways, and parking lots) that we use to get from one roof to another (Fig. 4). As it happens, the transport component now often exceeds the rooftop component, in terms of total impervious area created. For example, transport–related imperviousness comprised 63% to 70% of total impervious cover at the site in 11 residential, multifamily and commercial areas where it had actually been measured (City of Olympia 1994). This phenomenon is observed most often in suburban areas, and reflects the recent ascendancy of the automobile in both our culture and landscape. The sharp increase in per capita vehicle ownership, trips taken, and miles traveled have forced local planners to increase the relative size of the transport component over the last two decades.

FIGURE 4: ROOFTOP AND TRANSPORT COMPONENTS OF TOTAL IMPERVIOUS COVER



The dominance of the transport component of imperviousness (hatched lines) over the rooftop component (black) is evident in the typical residential and commercial site plans shown above.

Traditional zoning has strongly emphasized and regulated the first component (rooftops) and largely neglected the transport component. While the rooftop component is largely fixed in density zoning, the transport component is not. As an example, nearly all zoning codes set forth the maximum density for an area, based on dwelling units (=rooftops). Thus, in a given area, no more than one single family home can be located on each acre of land, and so forth. Density zoning has become popular as it allows planners to accurately forecast future wastewater, drinking water and transport needs in a community as a simple multiple of the average number of people residing in each dwelling unit. It is, however, a poor choice for assessing the cumulative impact of development on streams. The inadequacy of density zoning is due to the fact that it only measures rooftops and neglects the larger transport component of imperviousness.

Indeed, the creation of roads, parking and driveways, which constitute such a large share of total impervious cover, is not explicitly considered in the zoning process.

Consequently, when impervious cover is measured over a particular zoning category, a wide range of values are frequently found. As one example, the imperviousness associated with medium density single family homes can range from 25% to nearly 60%, depending on the street layout, parking and site design. Such a wide range suggests that significant opportunities exist to reduce the share of impervious cover generated by the transport component.

Management of Pervious Areas

While impervious cover clearly is a dominant force in urban watersheds, management of pervious areas should not be ignored or neglected. Pervious areas are very diverse in size and vegetative cover. Each community has a unique mosaic of forest, wetlands, meadow, lawn, turf, landscaping and vacant lots. While many of these pervious areas are green, their soils have been highly disturbed and compacted, and tend to produce greater rates of runoff than has been traditionally assumed (Pitt 1987). Moreover, pervious areas are frequently interlaced with impervious ones, creating an “edge effect” along roads, sidewalks and parking lots (Schueler 1995). This creates an opportunity for pollutants to migrate from pervious areas to impervious ones, in the form of fertilizer or pesticide runoff, drift of leaves, pollen and grass clippings, erosion and snowmelt. About a third of all pervious areas in the urban landscape can be classified as “high input” turf, that receive high rates of irrigation and fertilizers and insecticide applications (Schueler 1995). Although more research is needed, recent monitoring has demonstrated a link between the application of weedkillers, insecticides and nutrients to lawns and their presence in urban streams.

It is therefore important to recognize that while impervious cover is a very important management tool for urban watersheds, the possible impact of pervious areas should not be neglected. Communities should invest in outreach efforts that promote less fertilization and pesticide use on public turf and private lawns.

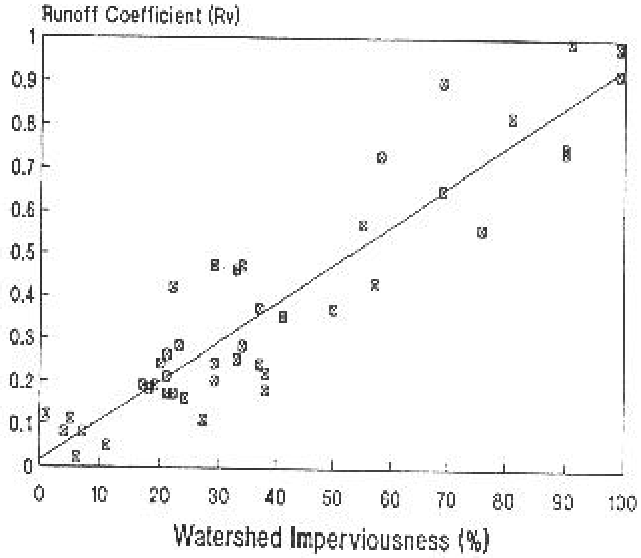
Imperviousness and Runoff

The relationship between imperviousness and runoff may be widely understood, but it is not always fully appreciated. Figure 5 illustrates the increase in the site *runoff coefficient* as a result of site imperviousness, developed from over 40 runoff monitoring sites across the nation. The runoff coefficient ranges from zero to one, and expresses the fraction of rainfall volume that is actually converted into storm runoff volume. As can be seen, the runoff coefficient closely tracks percent impervious cover, except at low levels where soils and slope factors also become important. In practical terms, this means that the total runoff volume for a one acre parking lot ($Rv=0.95$) is about 16 times that produced by an undeveloped meadow ($Rv=0.06$).

To put this in more understandable terms, consider the runoff from a one–inch rainstorm (see Table 3). The total runoff from a one acre meadow would fill a standard size office to a depth of about two feet (218 cubic feet). By way of comparison, if that same acre was completely paved, a one–inch rainstorm would completely fill your office, as well as the two next to it. The peak discharge, velocity and time of concentration of stormwater runoff also exhibit a striking increase when a meadow is replaced by a parking lot, as shown in Table 3.

The effect of impervious cover on stream hydrology is also very striking. More impervious cover directly translates into higher peak discharge rates, greater runoff volumes and higher floodplain elevations.

FIGURE 5: RUNOFF COEFFICIENT AS A FUNCTION OF SITE IMPERVIOUS COVER



Data from 44 small catchment areas in the US, from EPA's Nationwide Urban Runoff Program. Schueler, 1987.

TABLE 3: COMPARISON OF ONE ACRE OF PARKING LOT VERSUS ONE ACRE OF MEADOW IN GOOD CONDITION

Hydrologic or Water Quality Parameter	Parking Lot	Meadow
Curve number (CN)	98	58
Runoff coefficient	0.95	0.06
Time of concentration (minutes)	4.8	14.4
Peak discharge rate, 2–yr, 24–h storm (cu. ft/s)	4.3	0.4
Peak discharge rate, 100–yr storm (cu. ft/s)	12.6	3.1
Runoff volume from one–inch storm (cu. ft)	3450	218
Runoff velocity @ 2–yr Storm (ft/s)	8	1.8
Annual phosphorus load (lbs/ac/yr).	2	0.10
Annual nitrogen load (lbs/ac/yr).	15.4	0.8
Annual zinc load (lbs/ac/yr)	0.30	ND
Key Assumptions: **Parking Lot**: 100% impervious, 3% slope, 200 ft flow length, Type 2 Storm, 2–yr, 24–h storm = 3.1 in, 100–yr storm = 8.9 in., hydraulic radius = 0.3, concrete channel, suburban Washington 'C' values **Meadow**: 1% impervious, 3% slope, 200 ft flow length, good vegetative condition, B soils, earthen channel.		

While the effect is seen during both frequent and infrequent storm events, it is most pronounced during the smaller events. As Hollis (1975) notes, even relatively low levels of impervious cover (5 to 10%) are capable of increasing the peak discharge rate by a factor of 5 to 10 for storms smaller than the one year return storm.

It is thought that groundwater recharge decreases as impervious cover increases, due to lower infiltration during storms. This, in turn, should translate into lower dry weather stream flows. Actual data, however, that demonstrate this effect is rare. Indeed, Evett (1994) could not find any statistical difference in low stream flow between urban and rural watersheds, after analyzing 16 North Carolina watersheds. Simmons and Reynolds (1982) did note that dry weather flows dropped 20 to 85% after development in several urban watersheds in Long Island, New York.

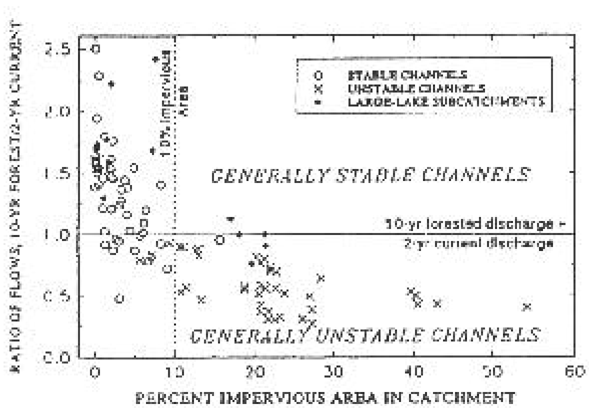
It should be noted that transport–related imperviousness often exerts a greater hydrological impact than the rooftop–related imperviousness. For example, rooftop runoff in residential areas is often spread out over pervious yards that are not directly connected to the storm drain system. As a result, these rooftops are considered to be *disconnected impervious areas*. During smaller storms, rooftop runoff can infiltrate into the soil, and less runoff is delivered to the stream. Pitt (1987) and Sutherland (1995) observed that disconnected impervious areas produce as little as a quarter to half the runoff of an equivalent area of connected impervious areas. Most roads and parking lots are directly linked to the storm drain system and are termed *directly connected impervious areas*. Nearly all the rain that falls on these surfaces is converted into stormwater runoff.

Imperviousness and the Shape of Streams

Confronted by more severe and more frequent floods, stream channels must respond. They typically do so by increasing their cross–sectional area to accommodate the higher flows. This is done either through widening of the stream banks, downcutting of the stream bed, or frequently, both. This phase of channel instability, in turn, triggers a cycle of streambank erosion and habitat degradation.

The critical question is at what level of development does this cycle begin? Recent research models developed in the Pacific Northwest (Booth 1991, and Booth and Reinelt 1993) suggest that a threshold for urban stream stability exists at about 10% imperviousness (Fig. 6).

FIGURE 6: URBAN STREAM CHANNEL STABILITY AS A FUNCTION OF WATERSHED IMPERVIOUS COVER (AFTER BOOTH AND REINELT 1993)



Watershed development beyond this threshold consistently resulted in unstable and eroding channels. The rate and severity of channel instability appears to a function of subbankfull floods (Hollis 1975, Schueler 1987, MacRae and Marsalek 1992), whose frequency can increase by a factor of ten even at relatively low levels of imperviousness.

A major expression of channel instability is the loss of instream habitat structures, such as the loss of pool and riffle sequences and overhead cover, a reduction in the wetted perimeter of the stream and the like. A number of methods have been developed to measure the structure and quality of instream habitat in recent years (Plafkin et al. 1989, Gibson et al 1993, and Galli 1993). Where these tools have been applied to urban streams, they have consistently demonstrated that a sharp threshold in habitat quality exists at approximately 10 to 15% imperviousness (Shaver et al. 1994, Booth and Reinelt 1991). Beyond this threshold, the physical quality of urban stream habitat consistently ranks as poor.

Imperviousness and Water Quality

Impervious surfaces collect and accumulate pollutants deposited from the atmosphere, leaked from vehicles, or derived from other sources. In some cases, impervious surfaces themselves become a significant source of pollutants (e.g., zinc desorbing from roof surfaces). During storms, organic matter, nutrients, metals, hydrocarbons, and bacteria are quickly washed off and rapidly delivered to aquatic systems.

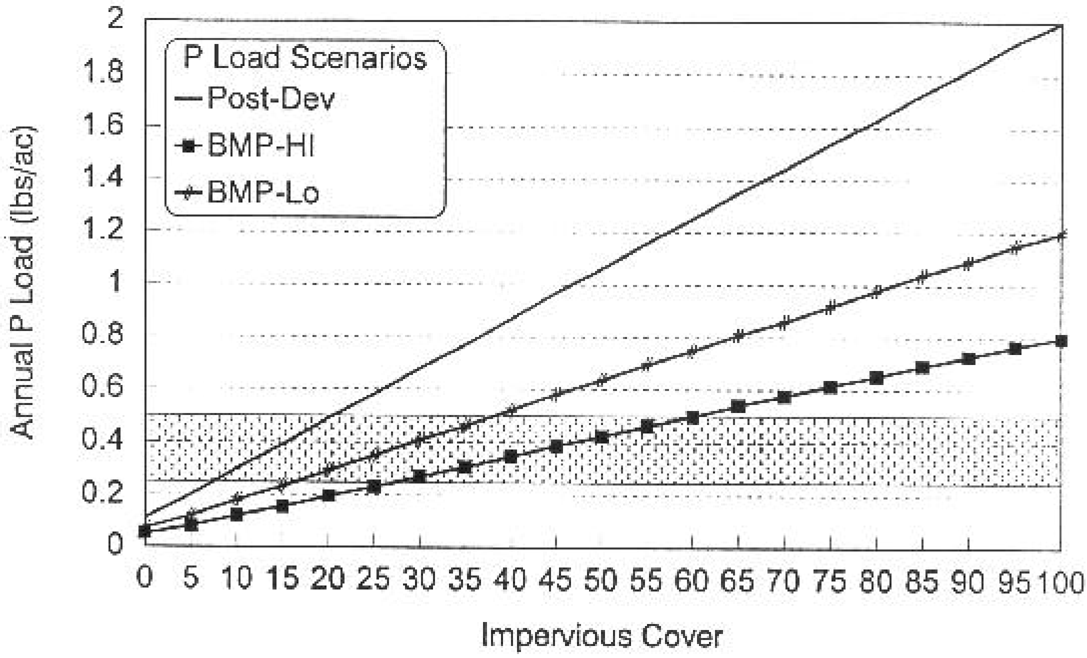
Monitoring and modeling studies have consistently indicated that urban pollutant loads are directly related to watershed imperviousness. Indeed, imperviousness is the key predictive variable in most simulation and empirical models used to estimate urban pollutant loads. For example, the Simple Method assumes that pollutant loadings are a direct function of watershed imperviousness, as impervious cover is the key independent variable in the equation. The water quality implications of this relationship are highlighted in Figures 7 and 8.

Threshold limits for maintaining background pollutant loads

Suppose that a watershed drains to a lake that is phosphorus–limited or to a coastal water that is nitrogen–limited. Also assume that the present background load of nutrients from a rural land use amounts to 0.5 and 2.0 lbs/ac/yr of phosphorus and nitrogen, respectively. The Simple Method predicts that urban runoff nutrient loads will exceed background loads once watershed imperviousness increases beyond 20–25%, thereby increasing the probability of nutrient overenrichment (eutrophication) in the lake or coastal water.

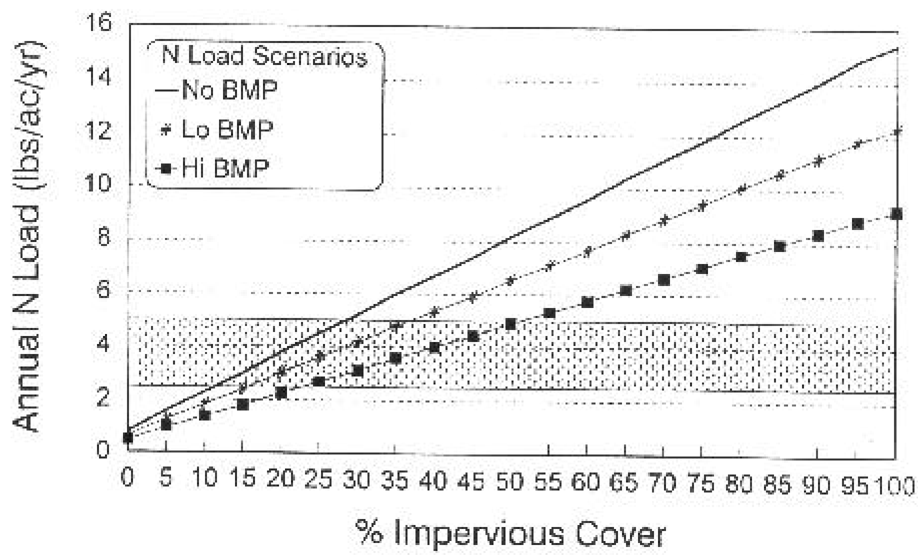
Urban nutrient load can be reduced when urban best management practices (BMPs) are installed, such as stormwater ponds, wetlands, filters or infiltration practices. Performance monitoring data indicate that these BMPs can reduce phosphorus loads by as much as 40–60%, and nitrogen loads by 20–40% depending on the practice selected (Figs. 7 and 8). The net effect is to raise the nutrient

FIGURE 7: THE EFFECT OF IMPERVIOUS COVER ON URBAN PHOSPHORUS LOAD UNDER SEVERAL SCENARIOS



Phosphorous loads computed using the Simple Method. The grey band indicates typical "background" phosphorous loads from undeveloped watersheds. The BMP-Hi line illustrates the impact in reducing P loads using BMPs with an average long-term removal rate of 60%. The BMP-Lo indicates a 40% removal rate.

FIGURE 8: THE EFFECT OF IMPERVIOUS COVER ON URBAN NITROGEN LOADS UNDER SEVERAL SCENARIOS



Nitrogen loads calculated using the Simple Method. Grey band indicates typical "background" nitrogen loadings from undeveloped watersheds. The effect of the most effective BMPs in reducing nitrogen loads is shown on the BMP-Hi line (average 40% removal). The BMP-Lo line is an average 20% removal.

threshold to about 35% to 60% impervious cover, depending on the removal capability of BMPs. Therefore even when effective practices are widely applied, we eventually cross a threshold, beyond which we cannot maintain predevelopment water quality.

Impervious reduction as a key element of a structural BMP system

Another simple calculation illustrates the benefits of reducing impervious cover, as one element of a pollutant reduction strategy. Consider that the estimated phosphorus load from a 60% impervious site is about 1.25 lbs/ac/yr (Fig. 9). If the same site was served by a BMP, such as a biofilter or sand filter, that could remove 40% of the phosphorus load, it would still have an annual export of 0.75 lbs/ac/yr—still well above our background load of 0.5 lbs/ac/yr. An identical phosphorus load rate would be generated simply by reducing impervious cover at the site from 60 to 37%, without constructing any BMPs. The combination of imperviousness reduction and the construction of effective BMPs, is able to keep net phosphorus export below background levels.

Runoff quality from transport and rooftop impervious cover

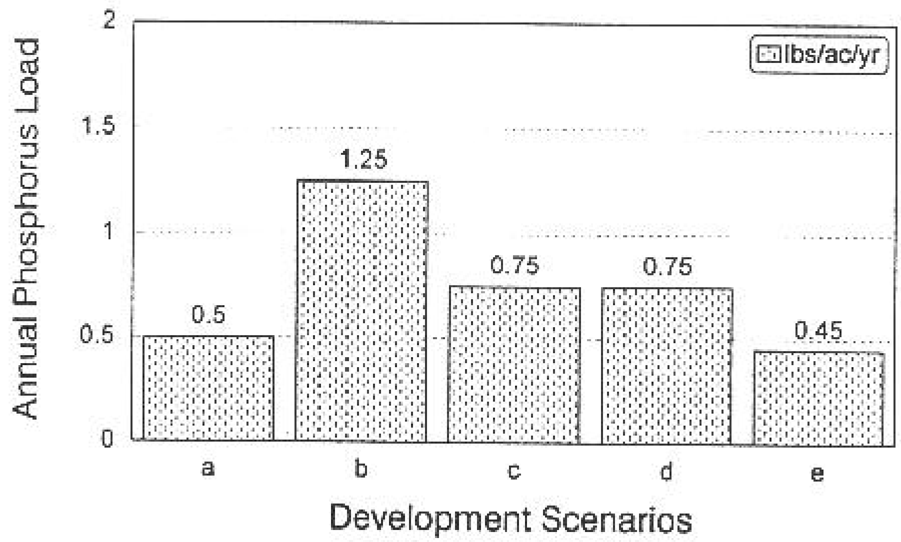
Recent monitoring studies suggest that the concentration of sediment, nutrients, bacteria, hydrocarbons and some trace metals are lower in rooftop runoff than in the roads and parking lots that comprise the transport component of imperviousness (Bannerman 1994). Indeed, many urban runoff 'hotspots' are associated with transport (e.g., vehicle maintenance operations and commercial parking lots). Two exceptions to this general rule are zinc and copper which are significantly higher in rooftop runoff than any other impervious surface (Schueler 1994b). However, for most other pollutants, a reduction in the transport component of impervious cover appears to have greater potential to reduce pollutant loads than rooftops.

Imperviousness and Stream Warming

Impervious surfaces both absorb and reflect heat. During the summer months, impervious areas can have local air and ground temperatures that are 10 to 12 degrees warmer than the fields and forests that they replace. Trees that could provide shade to offset the effects of solar radiation are usually absent.

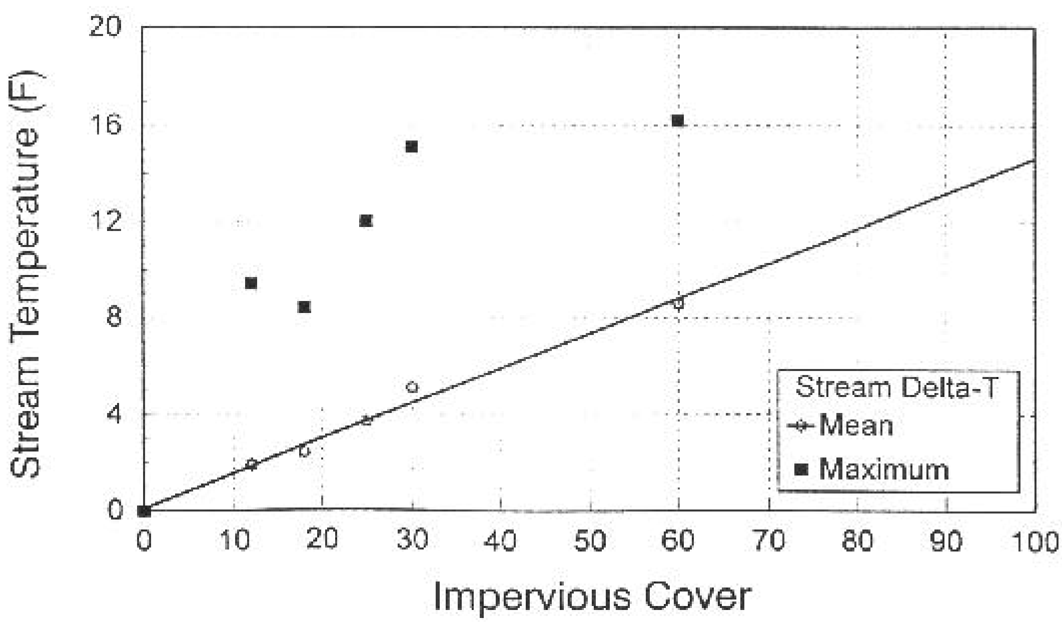
Water temperature in headwater streams is strongly influenced by local air temperatures. Stream temperatures throughout the summer are increased in urban watersheds, and the degree of warming appears to be directly related to the imperviousness of the contributing watershed (Galli 1990). Over a six–month period, Galli monitored five headwater streams in the Maryland Piedmont that differed in impervious cover (Fig. 10). Each of the urban streams had mean temperatures that were consistently warmer than a forested reference stream, and the size of the increase (delta–T) appeared to be a direct function of watershed imperviousness of the urban streams had a higher delta–T (mean hourly temperature). Other factors, such as lack of riparian cover and ponds, were also demonstrated to amplify stream warming, but the primary contributing factor was impervious cover (Galli 1990).

FIGURE 9: PHOSPHORUS LOADS UNDER DIFFERENT LAND USE AND BMP TREATMENT OPTIONS



Scenario a: background phosphorus load; scenario b: phosphorus load for a 60% impervious site; scenario c: 60% impervious site but with an effective BMP (40% removal); scenario d: site is configured to reduce imperviousness to 37%; scenario e: same as d, but with a BMP.

FIGURE 10: THE EFFECT OF IMPERVIOUS COVER ON STREAM TEMPERATURE



reference stream. Modified from Galli (1990).

Imperviousness and Stream Biodiversity

The health of an aquatic ecosystem is a strong environmental indicator of watershed quality. A number of research studies have recently examined the links between imperviousness and the biological diversity in streams. Some of the key findings are summarized in Table 4.

Aquatic insects

The diversity, richness and composition of the benthic or streambed community has frequently been used to evaluate the quality of urban streams. Not only are aquatic insects a useful environmental indicator, but they also form the base of the food chain in most streams and rivers.

Klein (1979) was one of the first to note that macroinvertebrate diversity drops sharply in urban streams in Maryland. He found that diversity consistently became poor when watershed imperviousness exceeded 10–15%. The same basic threshold has been reported in all other research studies that have looked at macroinvertebrate diversity in urban streams (Table 4). In each study, sensitive aquatic macroinvertebrates were replaced by species more tolerant of pollution and hydrologic stress. Stoneflies, mayflies and caddisflies largely disappear and are replaced by chironomids, aquatic worms, amphipods, and snails. Species that employ specialized feeding strategies—shredding leaf litter, grazing rock surfaces, filtering organic matter that flows by, and preying on other insects—were lost. Pedersen and Perkins (1986) observed that the diversity of feeding strategies was greatly reduced in urban streams.

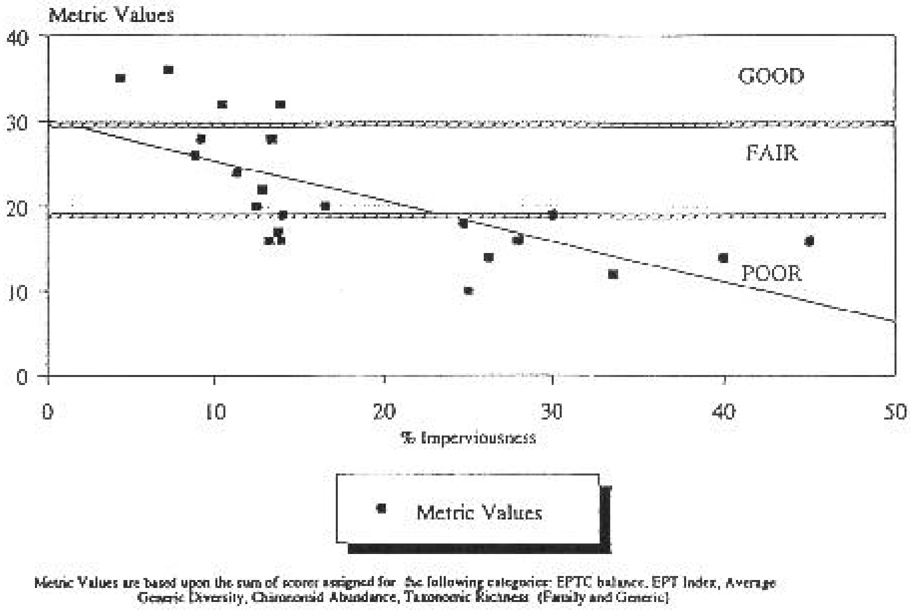
A typical example of the relationship between impervious cover and macroinvertebrate diversity is shown in Figure 11. The graph summarizes trends at 23 sampling stations in headwater streams of the Anacostia watershed (Schueler and Galli 1992). While good to fair diversity was noted in those streams with less than 10% imperviousness, nearly all stations having more than 12% imperviousness recorded poor diversity. The same sharp drop in macroinvertebrate diversity around 12–15% imperviousness was also observed in streams in the coastal plain and piedmont of Delaware (Shaver et al.1994).

Other studies have utilized other indicators to measure the impacts of urbanization on stream insect communities. For example, Jones and Clark (1987) monitored 22 stations in Northern Virginia and concluded that benthic insect diversity composition changed markedly after watershed population density exceeded four or more individuals per acre. This population density roughly translates to half–acre or one–acre lot residential land use—or perhaps 10–20% imperviousness. Steedman (1988) evaluated 208 Ontario stream sites and concluded that benthic diversity shifted from fair to poor at about 35% urban land use. Since "urban land" includes both pervious and impervious areas, the actual threshold in the Ontario study may well be closer to 7 to 10% imperviousness (Booth 1991). Steedman also reported that urban streams with intact riparian forests had higher diversity than those that did not, at the same level of urbanization.

TABLE 4: KEY FINDINGS EXAMINING THE RELATIONSHIP OF URBANIZATION ON STREAM DIVERSITY

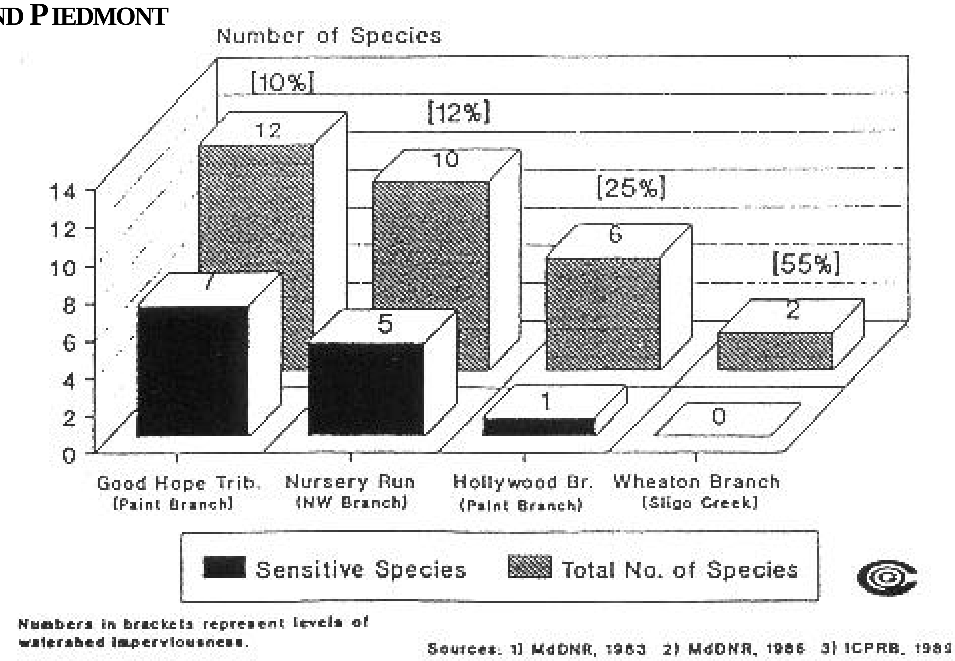
Ref.	Year	Location	Indicator	Key Finding
Booth	1991	Seattle	Fish habitat channel stability	Channel stability and fish habitat quality deteriorated rapidly after 10% I
Benke	1981	Atlanta	Aquatic insects	Negative relationship between number of insect species and urbanization in 21 streams
Jones and Clark	1987	N. Virginia	Aquatic insects	Urban streams had sharply lower diversity of aquatic insects, when human population density exceeded 4 persons/acre (estimated 15–25% I)
Limburg and Schmidt	1990	New York	Fish spawning	Resident and anadromous fish eggs and larvae declined sharply in 16 tributary streams that were more than 10% urban
Shaver et al	1994	Delaware	Aquatic insects	Insect diversity at 19 stream sites dropped sharply at 8 to 15% I
Shaver et al	1994	Delaware	Habitat quality	Strong relationship between insect diversity and habitat quality; majority of 53 urban streams had poor habitat
Schueler and Galli	1992	Maryland	Fish	Fish diversity declined sharply with increasing I, loss in diversity began at 10–12% I
Schueler and Galli	1992	Maryland	Aquatic insects	Insect diversity metrics in 24 subwatersheds shifted from good to poor beyond 15% I
Black and Veatch	1994	Maryland	Fish/insects	Fish, insect and habitat scores were all ranked as poor in 5 subwatersheds that were greater than 30% imperviousness
Klein	1979	Maryland	Aquatic insects	Macroinvertebrate diversity declines rapidly after 10% I
Luchetti and Fuersteburg	1993	Seattle	Fish	Marked shift from less tolerant coho salmon to more tolerant cutthroat trout populations noted at 10–15% I at 9 sites
Steedman	1988	Ontario	Aquatic insects	Strong negative relationship between biotic integrity and increasing urban land use/riparian condition at 209 measured stream sites. Degradation begins at about 10% I
Pederson and Perkins	1986	Seattle	Aquatic insects	Macroinvertebrate community shifted to chironomid, oligochaetes and amphipod species tolerant of unstable conditions
Steward	1983	Seattle	Salmon	Marked shift from less tolerant coho salmon to more tolerant cutthroat trout populations noted at 10–15% I at 9 sites
Taylor	1993	Seattle	Wetlands	Mean annual water fluctuation was inversely correlated to plant and amphibian density in urban wetland systems. Significant degradation was noted at approximately 10% imperviousness
Garie and McIntosh	1986	New Jersey	Aquatic insects	Drop in insect taxa from 13 to 4 with urbanization shift to collectors such as chironomids
Yoder	1991	Ohio	Aquatic insects	100% of 40 sites sampled had fair to very poor IBI scores that had urban runoff and/or CSO impact, compared to only 56% of 52 agricultural sites that had good–exceptional IBI scores

FIGURE 11: RELATIONSHIP BETWEEN IMPERVIOUS COVER AND AQUATIC INSECT DIVERSITY IN ANACOSTIA RIVER SUBWATERSHEDS



Various macroinvertebrate metrics in 23 headwater stream stations indicate a shift from good diversity to poor diversity as impervious cover increases. Data from Schueler and Galli (1992).

FIGURE 12: FISH DIVERSITY IN FOUR SUBWATERSHEDS OF DIFFERENT IMPERVIOUS COVER IN THE MARYLAND PIEDMONT



The number of fish collected in four small streams declines as impervious cover increases in this data set presented by Schueler and Galli (1992).

While the exact point at which stream insect diversity shifts from fair to poor is not known, it is clear that few, if any, urban streams can support diverse benthic communities at moderate to high levels of imperviousness (25% or more). For example, Benke (1981), Garie and McIntosh (1986), Yoder (1991) and Black and Veatch (1994) all failed to find stream insect communities with good or environmental indicator.

Fish surveys

Surprisingly, relatively few studies have examined the influence of imperviousness on fish communities in headwater streams. The results of one study are shown in Figure 12. Four similar subwatersheds in the Maryland Piedmont were sampled for the number of fish species present. As the level of watershed imperviousness increased, the number of fish species dropped. Sensitive species, defined as those with a strong dependance on the substrate for feeding or spawning, declined most rapidly. In particular, brown trout were lost when imperviousness increased from 10 to 12%, and four more species were lost when impervious cover increased to 25%. Significantly, only two species remained in the fish community at 55% imperviousness. Klein also found a negative relationship between watershed impervious cover and fish diversity in several dozen headwater streams in the Maryland Piedmont.

Salmonid fish species (trout and salmon) and anadromous fish species appear to be most negatively impacted by imperviousness. Trout have stringent temperature and habitat requirements and seldom are present in mid–Atlantic watersheds where imperviousness exceeds 15%. Declines in trout spawning success are evident above 10% impervious cover. In the Pacific Northwest, Luchetti and Feurstenburg (1993) seldom found sensitive coho salmon in watersheds beyond 10 or 15% imperviousness. Booth (1994) noted that most urban stream reaches had poor quality fish habitat when impervious cover exceeded 8–12%.

Fish species that migrate from the ocean to spawn in freshwater creeks are also very susceptible to the impacts of urbanization, such as barriers, pollution, flow changes and other factors. For example, Limburg and Schmidt (1990) discovered that the density of anadromous fish eggs and larvae declined sharply after a threshold of 10% imperviousness was surpassed in 16 subwatersheds draining to the Hudson River.

Imperviousness and Other Urban Water Resources

Several other studies point to the strong influence of imperviousness on other important aquatic systems such as shellfish beds, estuarine sediments and wetlands.

Even relatively low levels of urban development yield high levels of bacteria, derived from urban runoff or failing septic systems. These consistently high bacterial levels often result in the closure of shellfish beds in coastal waters. It is not surprising that most closed shellfish beds are in close proximity to urban areas. Indeed, Duda and Cromartie (1982) maintain that it is difficult to prevent shellfish closure when more than one septic drain field is present per seven acres—a very low urban density. Although it is widely believed that urban runoff accounts for many shellfish bed closures (now that most point sources have been controlled), no systematic attempt has yet been made to relate watershed imperviousness to the extent of shellfish bed closures.

Contamination of lake and estuarine sediments by metals and hydrocarbons also appears to be closely linked to urban development in many parts of the country. One indirect piece of evidence is the fact that nearly all trapped sediments within stormwater ponds and catchbasins show evidence of metal and possibly hydrocarbon enrichment, even at relatively low levels of upstream residential development (Schueler 1994a). Again, it would be interesting to compare pollutant concentrations in sediment profiles for small urban watersheds with different degrees of impervious cover, to see if some kind of threshold exists beyond which "clean" sediments cannot be maintained.

Taylor (1993) examined the effect of watershed development on 19 freshwater wetlands in King County, Washington, and concluded that the additional stormwater contributed to greater annual water level fluctuations (WLF). When the annual WLF exceeded 8 inches, the richness of both the wetland plant and amphibian community dropped sharply. This increase in WLF began to occur consistently when upstream watersheds exceeded 10–15% imperviousness.

Economics of Impervious Cover

Developers, homeowners and local governments all realize cost savings from reduced impervious cover. For developers, the benefits are clearly economic. Impervious cover is expensive to construct, and the only impervious cover that the developer is really able to sell are rooftops. Infrastructure, much of which consists of linear impervious surfaces such as roads, sidewalks, driveways and parking spaces, constitutes about half the cost of residential subdivision construction. Three large components of the residential infrastructure are roadbuilding, storm drainage and water and sewer service (Table 5). Significant cost savings can be achieved for each component when aggressive efforts are made to reduce impervious cover. For example, road length can be cut by 50 to 75% in cluster developments (Land Ethics 1994). Narrower road widths can also reduce road surface area by 25 to 35% (Chapter 6). At an average cost of over $100 to construct a linear foot of road, such reductions are extremely cost effective. Similarly, the cost of construction a single parking space (the stall plus the common share of the entire parking lot) costs over a thousand dollars. The cost savings achieved by eliminating just a few excess parking spaces can be very impressive.

Similarly, the size and capacity needed for the network of storm drain pipes and the best management practice system are a direct function of site imperviousness. Thus, for each increment of impervious cover that is reduced, developers gain a proportional reduction in the construction cost for these systems. Other cost savings include lower costs for clearing and grading and erosion control. Linear forms of infrastructure, such as water and sewer lines, are also shortened as road length declines. Some of the tools used to reduce impervious cover,

TABLE 5: THE ECONOMICS OF IMPERVIOUS COVER: UNIT COSTS OF SUBDIVISION DEVELOPMENT (FROM SMBIA 1990 AND OTHER SOURCES)

Subdivision improvement	Unit cost
Roads, Grading	$ 22.00 per linear foot
Roads, Paving (26 feet width)	$ 71.50 per linear foot
Roads, Curb and Gutter	$ 12.50 per linear foot
Sidewalks (4 feet wide)	$ 10.00 per linear foot.
Storm Sewer (24 inch)	$ 23.50 per linear foot
Driveway Aprons	$ 500 per apron
Parking Spaces	$ 1,100 per parking space ($2.75/sf)
Clearing (forest)	$ 4,000 per acre.
Driveway Aprons	$ 500 per apron
Sediment Control	$ 800 per acre
Stormwater Management	$ 300 per lot (variable)
Water/Sewer	$ 5,000 per lot (variable)
Well/Septic	$ 5,000 per lot (variable)
Street Lights	$ 2.00 per linear foot
Street Trees	$ 2.50 per linear foot

such as clustering, can also help a developer recover a salable lot that might have otherwise been lost to protect streams, wetlands or floodplains. While the exact cost savings vary depending on the size and layout of the subdivision, developers have a strong incentive to reduce impervious cover.

Property owners can also realize indirect economic benefits from reduced impervious cover. Needless impervious cover does not contributes to the quality of life or a sense of community. Many communities have found that efforts to reduce impervious cover result in more open or green space, as well as a more pedestrian friendly environment. Recent economic studies have shown that property values in well–designed cluster developments that incorporate open space appreciate at a more rapid rate than conventional (and more impervious) developments. The increase in property values ranged from 5 to 32% in three Northeastern studies (Land Ethics 1994). Future chapters will explore the many economic benefits of reduced impervious cover in greater detail.

Conclusion

Research has shown that imperviousness is a powerful and important indicator of future stream quality, and that significant degradation occurs at relatively low levels of development. The strong relationship between imperviousness and stream quality presents a serious challenge for urban watershed managers. It underscores the difficulty in maintaining urban stream quality.

At the same time, imperviousness represents a common currency that can be measured and managed by planners, engineers and landscape architects alike. It links the activities the individual development site with its cumulative at the watershed scale. With a knowledge of impervious cover, planners can make better site planning and watershed management decisions.

By itself, the high cost of creating impervious cover is a powerful incentive for planners, engineers, and developers to minimize its generation.

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